DIFFERENCES IN CASCADIA GREAT-EARTHQUAKE MAGNITUDES INFERRED FROM TSUNAMI-LAID SAND AND MICROFOSSIL ASSEMBLAGES BENEATH TIDAL MARSHES AT ALSEA BAY, OREGON

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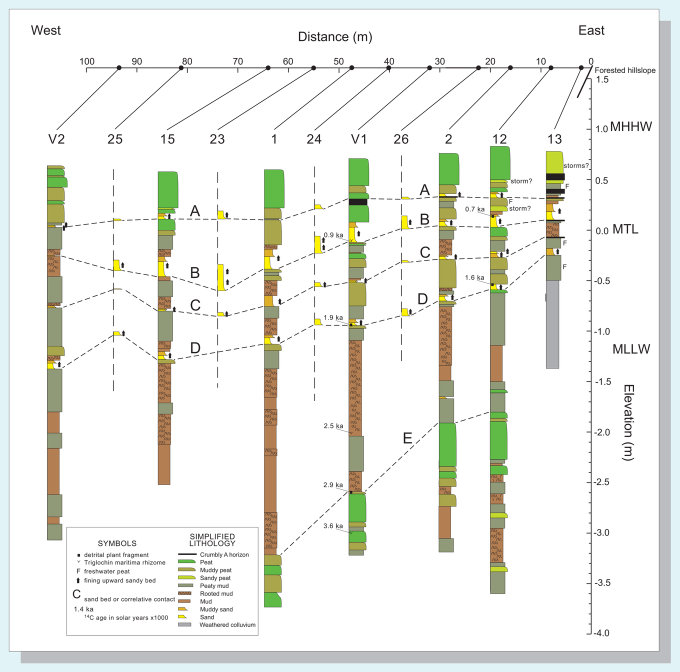
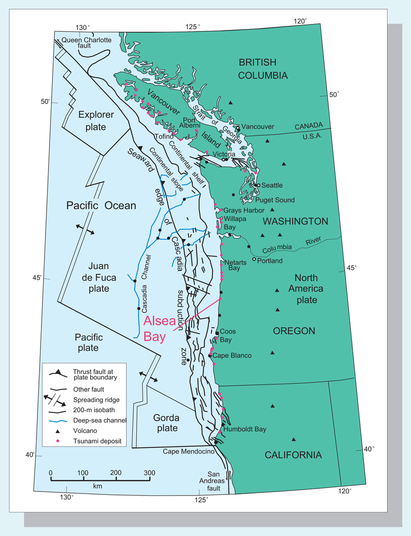


Simplified lithologies, tsunami sands A, B, C, and D, and sharp contact E in the middle transect of gouge and vibracores. Arrows show fining upward beds within sands that probably record one or more tsunami surges. Radiocarbon ages for cores V1 and 12 are shown in table. Discontinuous sand laminae above and below sand A in cores 12 and 13 may record storm surges.



Cascadia subduction zone (from Atwater et al., 1995 and Clague, 1997). Pink dots show sites with tsunami deposits that are probably correlative with some of those at Alsea Bay.

Tidal flat, low marsh, and middle marsh near the southern core transect looking north towards the middle and northern transects on the northeast shore of Alsea Bay.

ABSTRACT

Despite its importance to seismic hazard assessment in central western North America, the history of plate-boundary earthquakes at the Cascadia subduction zone is sketchy. Is all plate-boundary slip accommodated during magnitude-9 earthquakes that rupture much of the 1200-km-long plate boundary, or do magnitude-8 earthquakes create a more complex, segmented pattern of plate-boundary rupture? Widespread sheets of sand in stratigraphic sequences of intertidal wetland sediment mark tsunamis generated by Cascadia plate-boundary earthquakes. Assemblages of fossil diatoms and foraminfers above and below the sheets may yield measures of the amount of regional coseismic subsidence coincident with each tsunami. The greater the earthquake, the greater the rupture area and amount of coseismic subsidence.

Alsea Bay, on the Oregon coast about midway between Washington and California, is an important site for reconstructing Cascadia's earthquake history because the nearest comparable stratigraphic records of subsided wetlands and tsunami-laid sand lie >60 km to the north and south. In a 2-km-long marsh on the eastern edge of Alsea Bay, four widespread sheets of sand, dated at about 0.3, 0.8, 1.3, and 1.6 ka, cover peaty middle and high marsh deposits. The thickness and lateral extent of the four sand sheets suggest that they were deposited by Cascadia-generated tsunamis. Three of the sheets are overlain by muddy deposits like those of the low marsh or tide flat, but the lithology of peat above and below the 1.0-ka sheet suggests little change in intertidal environment at the time of the tsunami. Transfer functions derived from changes in the proportions of the diatoms and foraminifers in samples from above and below the sand sheets suggest about 0.4 m of sudden marsh subsidence coincident with the AD 1700 tsunami (sand A), but little permanent land-level change about the times of at least two of the other three tsunamis. The minimal land-level changes may be due to plate-boundary ruptures that were largely north, south, or seaward of Alsea Bay.

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Radiocarbon data for samples beneath the eastern Alsea Bay marsh

Calibrated age (cal yr BP at 2σ)[a]	Provenance interpretation[b]	Lab-reported age (14C yr BP at 1σ)[c]	Radiocarbon Lab No.	Core/ Exposure	Depth in core (m)	Description of dated material
Sand A						
310-0	close age	**170±80**	Beta-125097	E2	0.45	25x10-mm herb flower bud lying 5 mm above sand-peat contact
	close age	**205±50**	CAMS-84710	P12	0.51	Herb bud within peat at lower sand contact
Sand B						
840-640	minimum age	420±40[d]	Beta-125096	E2	0.57	12x15-mm leathery rhizome frag 8 mm above overlying mud-peat contact
	minimum age	590±60	CAMS-84712	P12	0.65	5 *Scirpus* sp., 2 *Carex* sp., and 3 other seed cases from 30 mm of peat above sand
	minimum age	**755±30**[d]	OS-25274	C12	0.67	About 15 decayed *Picea stitchensis* leaves in fragments from within sand
	minimum age	**770±60**[d]	CAMS-84711	P12	0.66	Decayed rhizome in lower 10 mm of peat above sand
	maximum age	1040±140	OS-26199	E2	0.57	20x10-mm woody stem casing or bark from overlying mud-peat contact
	close age	**855±40**	CAMS-84713	P12	0.80	Two separate *Juncus* sp. rhizomes at lower sand contact
	maximum age	1035±45	AA-26604	V1	0.84	Growth-position fibrous stem base of large herb at top of high-marsh peat
Sand C						
1420-1050	maximum age	**1360±90**	OS-35705	P12	1.08	Detrital piece of decayed rusty brown wood in middle of sand
	maximum age	1520±95	OS-35701	P12	1.07	Detrital piece of woody herb horizontal near top of sand
Sand D						
1720-1530	minimum age	**1530±40**[d]	GX-26077	E2	1.41	20-mm-long rhizome 5 mm above overlying sand-mud contact
	minimum age	**1530±50**[d]	Beta-125099	E2	1.41	6-mm-long decayed rhizome 3 mm below overlying sand-mud contact
	close age	**1690±50**	Beta-125095	C12	1.36	18 fragments of herb flower or bud 3 mm below top of sand
	maximum age	1850±50	Beta-125098	E2	1.53	15-mm-long pieces of *Triglochin maritima* and harpoon from lower contact
	maximum age	**1710±40**	OS-25275	E2	1.53	Cleanest 20-mm-long pieces of woody herb rooted in peat beneath sand
	maximum age	1935±45	AA-26603	V1	1.66	Decayed fragments of stems, leaves, and roots of soft herbs
Contact E						
	minimum age	2525±45	AA-26600	V1	2.91	In-place stem base and leaves of *Triglochin maritima*; 40 cm above contact
	maximum age	2755±45	AA-26601	V1	3.29	Stem base and rhizome of large herb at top of high-marsh peat
	maximum age	2860±90	Beta-125093	C10	2.69	20x15-mm immature cone of *Picea stitchensis*

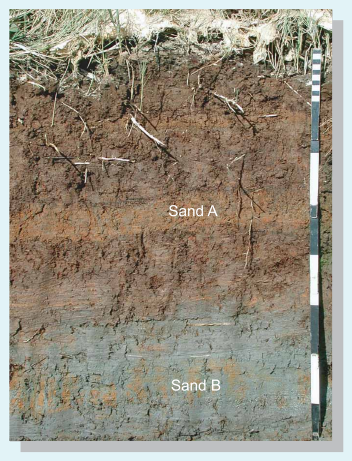
Ages are on unabraded fragments of flat-lying plant parts collected near the base or top of sandy units overlying high-marsh peat. Unless noted otherwise, samples are detrital and so ages are maximums. Submitted AMS samples weighed 2-45 mg and yielded ^{13}C values between -17.4 and -27.9‰.

[a]Best estimate of the times of tsunamis deposits at Alsea Bay, based on comparison of lab-reported ages in bold (third column) using the sequence analysis feature of the program OxCal (version 3.4, Bronk Ramsey, 1998; probability method). Bold ages selected on basis of material dated and stratigraphic context. Ages in solar years calculated using OxCal with the INTCAL98 dataset of Stuiver et al. (1998). NOSAMS' (OS), Tucson's (AA), and Lawrence Livermore's (CAMS) results from the Third International Radiocarbon Comparison show minimal offset from comparison means (e.g., Elder et al., 1998) suggesting that no additional interlaboratory variance (error multiplier; e.g., Taylor et al., 1996) is required for calibration. Calibrated ages show time intervals of >95% probability distribution at 2σ.

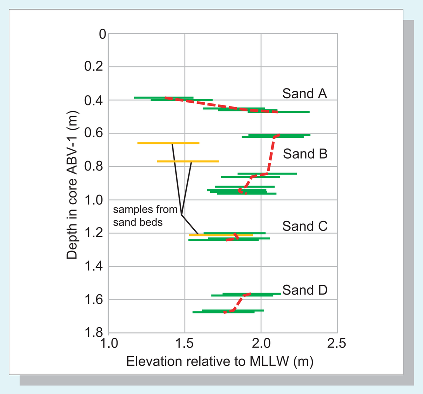
[b]Interpretation of the provenance, or stratigraphic context, of the dated sample relative to the time of great earthquakes and tsunamis. Maximum ages are on samples containing carbon judged to be older than the earthquake, minimum ages are on samples judged younger than the earthquake, and "close ages" are those on samples judged to contain carbon produced within a few decades of the earthquake.

[c]AMS (accelerator mass spectrometer) age reported by radiocarbon laboratory. Quoted errors for ages are the larger of counting error or target reproducibility error. Reported age of 755±30 from core 12 is the average of two ages on the same *Picea stitchensis* leaves.

[d]Rhizome probably grew after sand was deposited and so age is a minimum for sand deposition. Picea leaves may have been thrust into sand by a toppling tree.



Tsunami sand A (deposited "about 9 PM" on 26 January A.D. 1700; Satake et al., 2003) and tsunami sand B (1.0 ka) in an outcrop studied by Peterson et al. (1996) along the North Channel of the Alsea River 1.2 km southeast of our middle transect.



Past changes in land-level during great earthquakes recorded by changes in the proportions of intertidal foraminifers in vibracore V-1. We use transfer functions of foraminiferal assemblage data from immediately above and below four tsunami sands to estimate the amount of sudden subsidence during great earthquakes that produced the tsunamis. The functions were based on a 20-sample transect of modern foraminiferal data at the core site. Sand A is coincident with about 0.4 m of coseismic subsidence, but there appears to have been no permanent subsidence about the times of the tsunamis recorded by sands B, C, and D. Two samples suggest slight pre-seismic subsidence prior to the deposition of sand A. Limited funding prevented more detailed sampling throughout the core.

Past changes in land-level during great earthquakes (right column) inferred from changes in the proportions of intertidal diatoms in vibracore V-1. Transfer functions of diatom assemblage data through the core suggest little permanent land-level change following at least two, and perhaps three, of four great earthquakes coincident with four tsunami sand sheets. The functions were based on a 20-sample transect of modern diatom data at the core site. Sand A is coincident with about 0.4 m of coseismic subsidence. A single sample suggests about 0.7 m of subsidence about the time of sand C, but there appears to have been no permanent subsidence about the times of the tsunamis recorded by sands B and D.